Reactor Safety Assessment System: Summary of Methods and Experience

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1. Introduction

The statutory mission to ensure the health and safety of the public requires that the US Nuclear Regulatory Commission (NRC) maintain a capability to respond to any potentially threatening incident involving NRC licensed activities [1,2]. A Reactor Safety Team is set up at NRC to ensure this mission. One function of the Safety Team is to assess current and projected core and containment status. A real-time expert system, called Reactor Safety Assessment System (RSAS) is developed to help the team make its assessment during nuclear power plant incidents. The technical data, necessary for the assessment, is automatically received through the Emergency Response Data System (ERDS) and some minimal manual information obtained through the telephone Emergency Notification System.

2. General Description And System Objectives

The major functions of RSAS include (but are not exhausted by) the following:

- Monitor Critical Safety Functions (CSF) status.
- Control the availability of success paths needed to restore and maintain the associated CSFs.
- Analyze the effects of safety related support system failures on the success paths availability.
- Determine and prioritize data required from the plant under emergency to complete the core and containment status assessment.
- Identify critical conditions, which indicate the immanent degradation of safety related systems.

RSAS is a practical implementation of the Goal Tree Success Tree (GTST) methodology as a knowledge base of the expert system [3]. GTST can model complex system functions, interactions and interdependence, such as those in a nuclear power plant. The hierarchical structure of GTST simplifies the extension of critical safety functions to subfunctions, which are largely generic among classes of nuclear plants. The modular structure of the GTST simplifies the modification of the knowledge base, provides a consistent and exhaustive classification scheme for the storage and retrieval of the plant knowledge, and simplifies the verification and validation process.

The details of the knowledge structure and inference engine implementation have been discussed in our earlier publications [1-3]. The objective of this paper is to present the system from the user's prospective and show the role it plays in a nuclear power plant safety assessment and management.

3. System Implementation - User Interface Prospective

RSAS is implemented in the windows type user friendly environment, which is primarily mouse driven, although minor key-board input is also required. The system runs on two Sun SPARC stations, one of which is active and the other is in hot standby to provide redundancy.

As a part of the system initialization procedure, the user is asked to choose one of the operating mode, which can be either *ERDS Input, Training, or System Manager* (the latter is used for editing the generic and plant-specific models). He is then prompted to specify the *Data Input Mode* and *Interval*. In the Training mode, an option is available to input data from a previously recorded data file, which makes it possible to thoroughly analyze the accident development process. Finally, the NPP of interest should be chosen from the list of available plants.

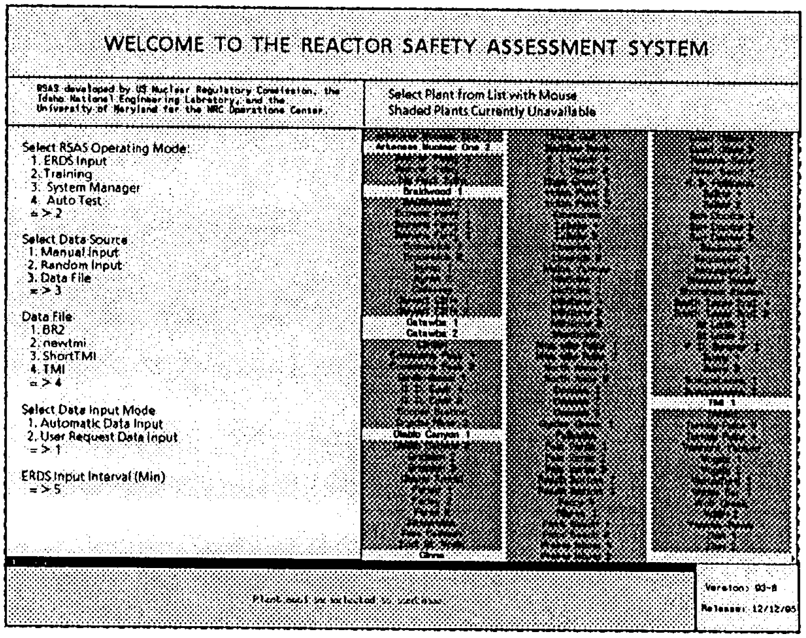

Fig. 1: RSAS Initialization Screen

RSAS is not supposed to be used for assessing the licensee's actions to mitigate an accident; neither does it model the plant specific operational characteristics. The user has to agree to these limitations to be able to proceed with the system initialization. The initialization process gets completed with the manual input of some parameters, which either require the expert's judgment or can not be supplied by ERDS.

The Critical Safety Functions are lined up at the top of the Assessment screen (see fig. 2). They are **Reactivity Control, RCS Inventory Control, RCS Pressure Control, RCS Transport Control, RCS Integrity control** and **Heat Sink Control.** To provide redundancy, the status of each CSF is determined through two independent logic trees, one of which (the **Equipment Tree**) is based on the physical availability of the hardware units comprising the emergency related systems of an NPP, and the other one (called the **Parameter Tree)** is based on the ERDS parameters measured at critical points of the reactor and its cooling system. The possible node statuses of the Equipment Tree are *Confirmed Available, Assumed Available, Conditional, Unavailable, and Unknown,* while the Parameter Tree nodes can be either *Degraded, Degrading, Normal, Improving, Conditional, and Unknown.* In case of the inconsistency between the statuses of the two top nodes, a Conflict Message is generated to alert the user.

For each node there exist the **Node Description** and the **Node Status** frames. The **Description** frame contains the *Entry Condition Rule,* the *Status Source* (e.g., Children, Manual) and *Rules,* the *Default Logic* and *Logic Rules,* and the name(s) of other node(s) referenced by the node under consideration. The **Status** frame depicts the *Condition Status* (if applicable), the definition of the *Active Status Rule,* setpoints and parameters involved in the rule, and other relevant information.

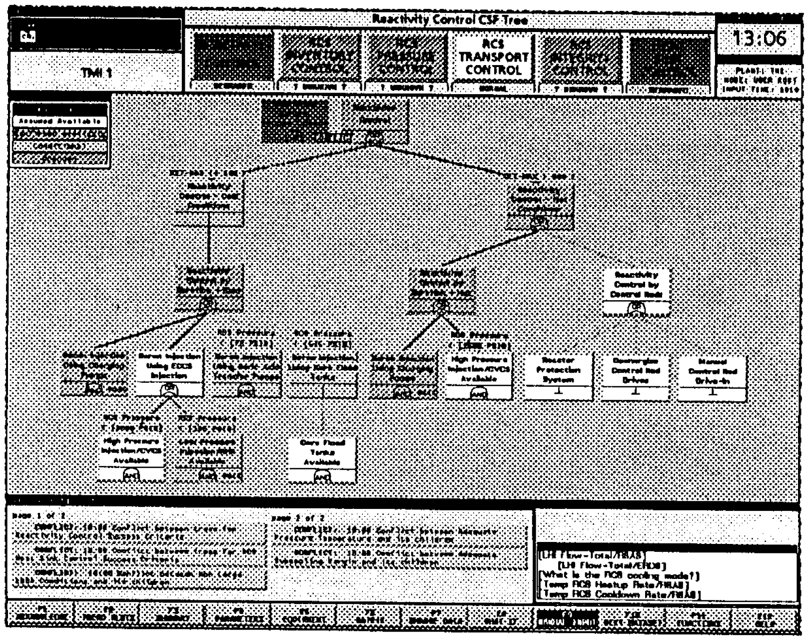

Fig. 2: The GTST Model of the Reactivity Control CSF

The bottom layer of the Assessment Screen represents RSAS Function Keys used to activate a number of features. The **Acknowledge** key is used to confirm that the user's attention has been attracted to a flashing object on the screen (such as *Degraded* status of a node, a Conflict message, etc.). The **Trend Plots** function key opens a 3x2 array of windows used to plot the parameter values as they change in time. Each plot supports up to 2 parameters, which can be picked by the user.

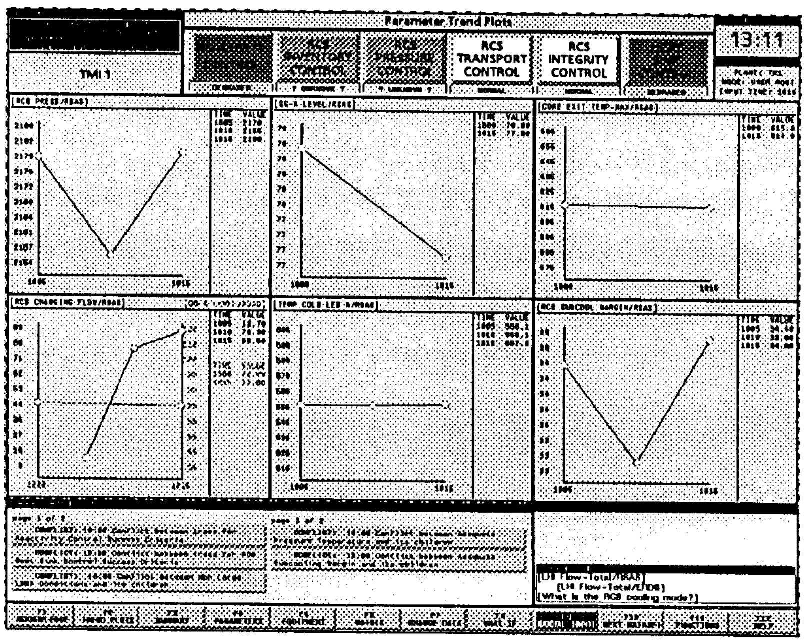

Fig. 3: Parameter Trend Plots

The **Parameters** function key is in place to display RSAS parameters either in the *Table* or the *Diagram* format. The *Diagram* format relates major parameters with the mask of a given NPP to provide better informativeness.

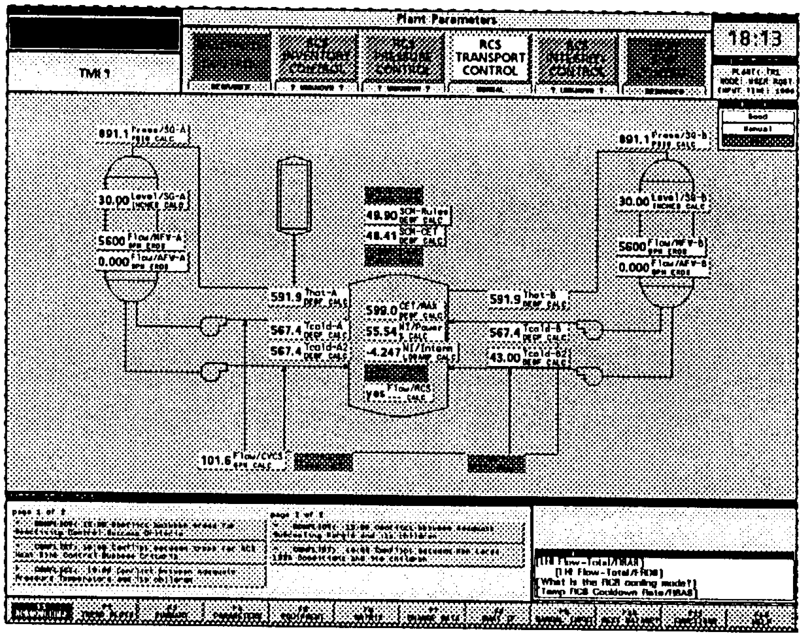

Fig. 4: The Plant Diagram

Each parameter listed in the *Table* can be retrieved through the **Description** frame, which holds the information on parameter's *Definition, Unit of Measure, Range* of possible values, *Life-Time, Criticality, Trend Prediction Coefficients* and other important characteristics. The Parameter **Status** frame holds the current *Value, Rate of Change,* and other data. The parameter **History** frame depicts the past values of major parameter characteristics as they evolved in time.

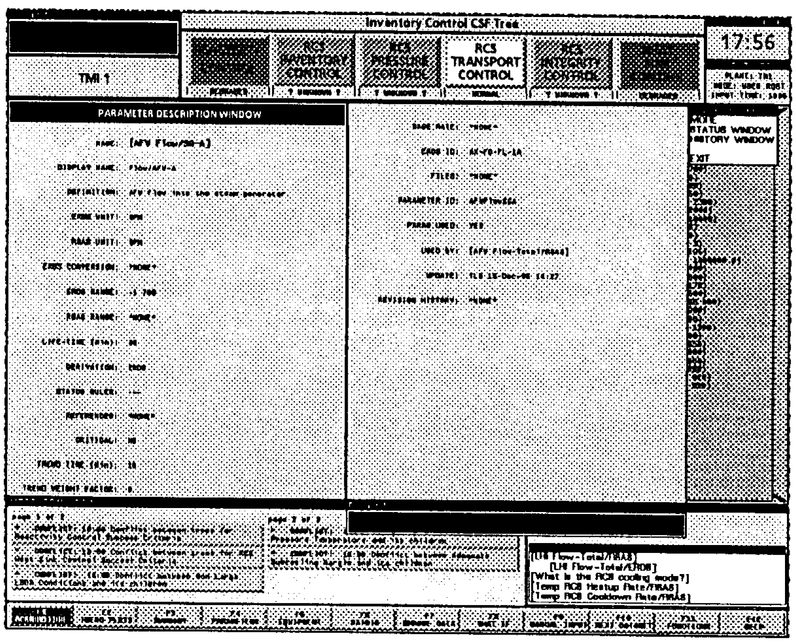

Fig. 5: Parameter Description Window

The **Equipment** table function key lists all hardware units used to model the system's knowledge. Each entry in the table is color coded to reflect the status of a particular device, and is mouse sensitive to manually provide the status update. The table entries are dynamically linked to one another to show how (for example) the failure of certain components effect the status of other components.

The **Matrix** function key opens the Support System Matrix -- an efficient and convenient tool to analyze the low level system interdependencies. Major components providing the electrical and cooling support are lined up in a vertical row at the left side of the screen, while the front line system equipment is shown in a horizontal raw at the top of the screen. The connecting lines are color coded (blue for cooling, red for electrical), and go horizontally from a child and then vertically to a parent. For each front-line system component, the analysis of the effect of failures from all combinations of support elements is established in the matrix. The detail contained in the matrix is limited to systems defined by the GTST model.

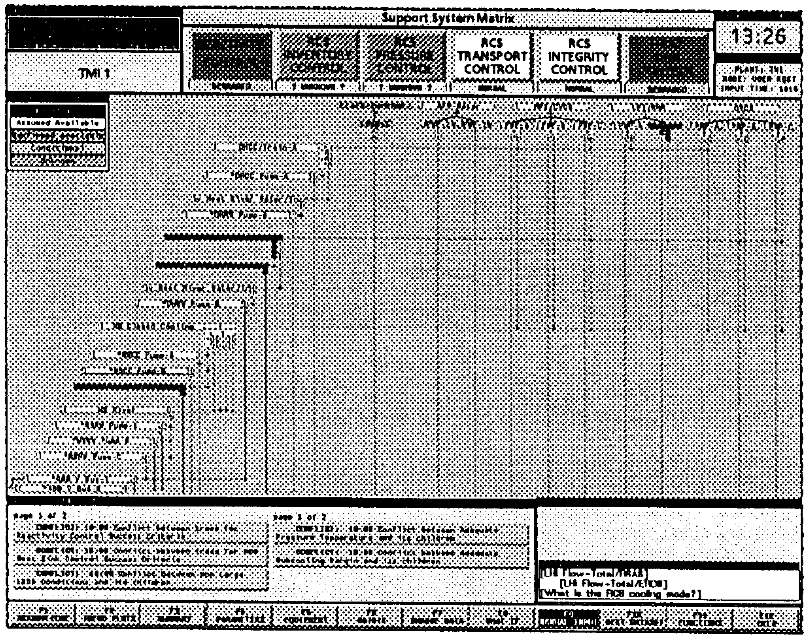

Fig. 6: The Support System Matrix

The **Change Data** function key allows modifying parameter values in terms of bringing the last data set or changing several historical values associated with an ERDS parameter. This feature is designed primarily for testing purposes. The **What If** function key initiates the respective facility to manually change the input data as desired, and then restore it to the original state. It can be found useful to work out possible scenarios of the accident development and management. The **Manual Input** is in place to allow the user to input values for unknown and manual parameters and setpoints.

The **Next Data Set** function key is used to input a new data set when reading data from a pre-recorded file, or to force the following data set from ERDS (thus shortening the data input interval). Finally, the **Functions** key provides a number of auxiliary features (changing data input mode, resetting the system initialization, making hard copies of varies modules of interest, etc.), and the **Help** function key contains definitions of basic concepts as well as the list of acronyms and abbreviations used in RSAS.

4. Concluding Remarks

Due to the restricted size of this paper, we limited the description of the system to its basic features in the *run* mode. A set of tools have been developed to create the plant-specific models of NPPs. These tools provide quick and efficient way to modify one of the two available generic models (PWR and BWR) to reflect the peculiarities of particular plants. As it was mentioned above, the GTST generic structure allows for modifying the low-level knowledge modules without violating the Knowledge Base integrity. The information about the specifics of an individual plant can be obtained from the Plant Information Books available at NRC.

RSAS is currently undergoing the final testing program and will be put into operation at the US NRC in the near future.

5. References

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2. Sebo D., D. Marksberry, and M. Modarres, "RSAS: A Reactor Safety Assessment System", Proceeding of the 7th Power Plant Dynamics, Control, and Testing Symposium, May, 1989.

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